Australian Nuffield Farming Scholars Association

2003 SCHOLARSHIP

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Topic: Balancing Soil Nutrients

Sponsored By:

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Executive Summary

Soil nutrients are an important input on any farm and they represent a major cost to agriculture. There is in excess of 140million tonnes of fertiliser consumed around the world every year and if we are to feed an ever increasing population this figure will only rise in the future.

Along with this increased usage, there is ever increasing pressure for farmers to use these nutrients in an environmentally responsible manner.

These two factors mean that as farmers we have to have these nutrients in balance with our crop yields. We have to have adequate nutrition to ensure that we optimise yield and are therefore profitable, but have to avoid over fertilising, risking financial loss and environmental damage.

Before you can balance any nutrients you have to firstly have the means to accurately measure them. It is this drive for measurement that led me to study the process of "Balancing Soil Nutrients".

I initially began looking at the existing technology we had available through standard soil testing and also grid sampling and found that they were unlikely to deliver the sort of precision required for the optimum placement of fertiliser and will therefore fall short of future environmental standards and will also miss out on a lot of increased profit that is available through the GPS driven precision ag style of farming.

The advent of GPS and its adaption to agriculture has given us the opportunity to lift the level of precision involved in nutrient testing, but I feel that the initial phase of zonal management will only be a stepping stone to some of the site specific management that is now coming forward. The zonal management system suffers from two major challenges - firstly in delineating the zones and secondly with the amount of variation within the zones commonly being as high as that between zones.

Two of the most exiting prospects I looked at in my study tour were associated with site specific management.

Through the development of the mobile pH testing machine we now have the ability to measure pH variation across paddocks to an infinitely variable density at a reasonable price.

The management of nitrogen through sensor technology or through the use of satellite imagery is another major step forward in the management of one our most important nutrients.

Some of the technology we now have available, such as the N Sensor from Oklahoma, can measure nitrogen variation down to 0.4m and while none of the systems I looked at were perfect, we are certainly at the start of some exciting new work with nitrogen.

With an improving ability to predict at least probabilities of rainfall, we can now start to prescribe fertiliser recommendations for crops rather than use the old replacement methods.

This ability will be required by farmers in the future as they strive to remain competitive, but equally important this level of preciseness will also be required by the general public, government regulators and our consumers as we all work towards a better environment.

My report covers the reasons that lead me to believing that this level of management will be demanded in the future by, not only farmers who are serious about remaining viable, but also consumers, environmentalists and policy makers that are equally as serious about preserving the environment we live in.

Acknowledgments

Until you start something like this acknowledgements report, you don't realise the number of people involved in sending one person around the world on a Nuffield scholarship.

I have had a fantastic time on both the six week core study tour and my personal tour.

I have met a lot of interesting and well informed people and seen things that I would never have seen without the Nuffield experience.

The first group of people to thank for this opportunity are the Nuffield organisation. The work that is put in by the Directors, ably led by Brendon Smart and CEO Bryan Clark and his assistant Janette Lees gave us all an experience we will never forget. As we travelled with scholars from around the world we soon realised that the Australian Nuffield organisation is truly the best in the world. They have done a fantastic job in lifting the profile of Nuffield here and transforming it into a large operation involving 11 scholars each year.

My sponsors the Grains Research & Development Corporation (GRDC) have played a big part in helping raise this profile. They not only provided sponsorship for myself, but two other scholars as well and give the Nuffield organisation a very thorough coverage through their magazine - Ground Cover. I would like to take this opportunity to thank them for their involvement and particularly the part they played in my trip and also the ongoing work they do towards a better grains industry here in Australia.

Sometimes you just need a little push to get things started and I guess that was the case for me with Nuffield. I had been looking at Nuffield from afar for sometime and not doing much with it until I received an invitation to attend one of their information nights. Fellow Nuffielder Tim Hutchings was responsible and I owe him a great deal for his encouragement and help with my application.

I would also like to thank my referees Geoff Pitson and Lisa Castleman Cary for their help in putting my application together.

While you are away there is a lot of pressure put on the people left at home. I would like to especially thank my wife Simone for her work in running a farm by herself for the first time and balancing this with raising three children. She did a magnificent job and I thank her very much for the hardships she put up with while I went in the pursuit of knowledge.

I would also like to thank the people that helped her along the way. Our three children Grace, George and Bill, our friends and relations that helped out and my father Walter who was here helping to run the farm.

Simone also had some excellent agronomic help on the farm and I would like to thank Heidi Gooden and Geoff Pitson for their help while I was away.

The core study tour was one of the highlights of my Nuffield experience. I spent six weeks touring around the world with eleven other Nuffield scholars visiting Embassies in the US, looking at 40,000ac vegetable farms, robots milking dairy cows, talking with ambassadors, but by far the best part of it was the eleven other people I shared the trip with.

The knowledge that I gained from these guys and the friendships I made is something that I doubt I will ever repeat and I would like to thank them for the experience.

People really do make the difference and I would like to thank everyone that helped me along the way with my personal study tour. I stayed with a lot of different people and enjoyed a great reception wherever I went. There are so many people that I need to mention here that it would take up most of my report, so I will thank you as a group for all for the accommodation, the friendship, the meals and of course the knowledge that you shared with me during my trip.

Lastly I would like to thank John Angus, Tony Good, Ann Hamblin, Mark Peoples, Jon Medway and everyone in the Nuffield organisation for their help in putting my contacts together for my personal study tour. It was a very valuable learning experience and the contacts are something I will have for the rest of my life.

Aims\Objectives\Study Goals

My choice of study topic came about through a frustration with our current use of soil testing technology and a lack of understanding about precision agriculture and the role it could play in balancing soil nutrients.

We have been using the standard soil test for many years and had really only been using it as a tool for monitoring pH and phosphorous levels. There was a whole lot of information on this test that was not utilised and none of the information was really used for devising fertiliser plans. All my planning for fertiliser use was based on replacing nutrients removed by the crop.

I wanted to look at ways of better utilising the soil test and to see if there was a better way of obtaining the information required to formulate a fertiliser plan.

Nitrogen has become an increasingly important nutrient in broadacre farming and we have tried many different methods of measuring the nitrogen status of our soils.

We began by using the NIR tissue test, had progressed to the deep soil nitrate test and now have thrown all technology out and gone back to the humble tiller count for our nitrogen needs. I felt that there must be a better way of managing this increasingly important nutrient and that technology could help give us a more objective means of measuring our nitrogen status.

In the search for more information on our soils I had used an electro magnetic survey of our farm. I had used this information to try and form soil zones and to put a little more science into our soil testing. To date I had only used this to form lime application maps and even this was not proving a great success. I felt there was a lot more information to be gained from this valuable piece of information and was keen to explore these possibilities.

It has been a very similar story with yield mapping. I had been watching other growers work with this technology and not using it with much purpose. We had commenced our own yield mapping a year ago and the experience was the same – a lot of coloured maps and no idea of what to do with them.

The final driving force behind “balancing soil nutrients” was the trace element issue. As our yields have increased over the years these minor nutrients were beginning to play an increasingly important role in our crop production. Zinc in particular was being recommended in the Riverina, but current recommendations were based on a “throw a bit out every couple of years” type theory and I felt there was much more to be learnt regarding this issue.

The final part of my study was a tour to the Ukraine. It was totally unrelated to the search for information on soil nutrients, but the opportunity arose and I felt it was too great to overlook.

I guess there was a fascination with looking at one of the old communist states, but I also wanted to see if this part of the world was a serious threat to the export orientated farming of countries like Australia.

Introduction

Balancing soil nutrients is an important part of any farming operation. Without a balanced soil crop yields will be reduced, money wasted on unnecessary inputs and the environment will be put at risk; but before we can balance nutrients we have to be able to measure them.

The main focus of my report is the measuring of these essential soil nutrients and the subsequent fertiliser recommendations arising from them.

Historically nutrient management in the cropping zones of Australia has been based on a replacement type method. This was a simple method and involved using yield averages for a district, farm or even paddock level, multiplying them by the nutrients contained in the grain and then calculating the total nutrients removed (see table below).

The Nutrition of Crops

TABLE 5.7 Nutrient content of some important crops (after Aldrich and Leng, 1969)

Crop and yield of grain (kg/ha)	Plant part	Nutrient content (kg/ha)					
		N	P	K	Ca	Mg	S
Barley 5,440	grain	97	19	23	2.8	5.5	9
	straw	42	5.5	68	22	5.5	11
	Total	139	24.5	91	24.8	11	20
Maize 5,440	grain	99	18	24	12	14	11
	stover	74	12	88	20	13	8
	Total	173	30	112	32	27	19
Soybeans 5,600	grain	413	42	127	20	20	11
Wheat 5,600	grain	138	19	35	2.8	17	9
	straw	55	6	80	17	9	13
	Total	193	25	115	19.8	26	22

These nutrients are then replaced with the following year's crop, in order to maintain the long term balance of the soil. Regular soil testing on a paddock average basis is then used to substantiate current fertiliser regimes.

In my research into balancing soil nutrients, I have been lead more and more into precision ag as a means of better managing these soil nutrients.

Precision agriculture involves turning the current replacement method of nutrient management on its head and moving to a forecasting style of nutrient management ie predicting crop yield and placing a prescription of fertiliser with the plant to achieve this yield.

To do this we need to have an accurate method of forecasting crop yields, which involves predicting weather and the potential of different soil types to achieve these yields.

While weather is something that still requires a lot of research, looking at the potential of our soils is something that can be done now with current technology with some of the nutrients we use.

In my paper on soil nutrients I will begin by working through some of the currently available methods of soil testing and their limitations and then moving onto the emerging precision ag technology.

Measuring Soil Nutrients

THE PADDOCK AVERAGE SYSTEM

The paddock average system has been the benchmark system for analysing soil nutrients for many years.

The system is still an excellent tool for monitoring long term fertiliser programs especially phosphorous, but there are a number of factors to be wary of when using this method of soil analysis.

Firstly the sample must be taken from uniform areas of the paddock, if there are distinctly different soil types or topography within the paddock then multiple samples should be taken.

The standard W pattern should be used across the paddock and a minimum of 25 – 30 cores should be taken to achieve a representative sample.

The samples should be taken at the same time of the year to reduce the temporal variation experienced with some of the soil nutrients. Soil pH, phosphorous, potassium, manganese and sulphur can all vary in their levels at different times of the year.

Moisture conditions can also have a large affect on nutrient levels and dry conditions will lower the readings of pH, phosphorous and potassium.

The depth of sampling combined with the cultivation practice can also have a large impact on soil test results. Regular direct drilling leads to a concentration of insoluble nutrients such as phosphorus in the topsoil, while other more soluble nutrients such as nitrogen and sulphur can be down at greater depths than are being tested.

There should always be a lag time between applying fertiliser and testing to avoid picking up concentrated bands of fertiliser and skewing results; suggested times for different fertilisers are as follows:

N, P, K, and Mg	-	8 weeks
Slurry's	-	12 weeks
Lime	-	12 months

The system has some severe limitations in measuring nitrogen and sulphur due to a number of facts.

Firstly there is huge variation across paddocks with both these nutrients; research at Oklahoma State University (Bill Raun et al) showed that nitrogen can vary from the maximum reading in a paddock to the minimum reading within 0.4m.

The second problem with measuring these nutrients is that there is a huge variation in their levels throughout the year (temporal variation) and measurements can be severely affected by the time of sampling.

GRID SAMPLING

Grid sampling is basically an extension of the paddock average or standard soil test, but instead of the individual core samples being combined and then averaged, they are kept separate and tested individually.

Sampling densities vary greatly depending on the operator and the level of precision required, but a typical range is 1 sample / 0.25 – 1.0ha.

The grid sampling system has a couple of major faults firstly is the cost. The "Australian Soil Fertility Manual" has produced a table that has included the cost of managing a 1ha block in a grid sampling method and you can see from this that the cost to accurately sample for some soil nutrients is prohibitive.

TABLE 12.2 Examples of soil sample spacings and analytical cost in Australia to carry out spatial predictions to sufficient accuracy.

Required sample spacing (m) and analytical cost ($/ha) of samples for a 1 ha field if managing a:

Measurement	10 m block		100 m block	
	No. of Samples (a)	Cost $/ha	No. of Samples	Cost $/ha (a)
pH	11.1	204	1	18
C (dag/kg) b	20.7	460	1.6	36
N (mg/kg) b	> 100	> 2290	6.2	185
P (mg/kg) b	> 100	> 2250	8.7	196
K (mg/kg) b	30.9	599	1.4	27

Note that sampling costs, sample preparation and delivery to the laboratory are additional costs not taken into account.

(a) Average and range of analytical costs per sample in Australia: pH $18.40 (8.00–35.00); C $22.20 (10.00–23.00);

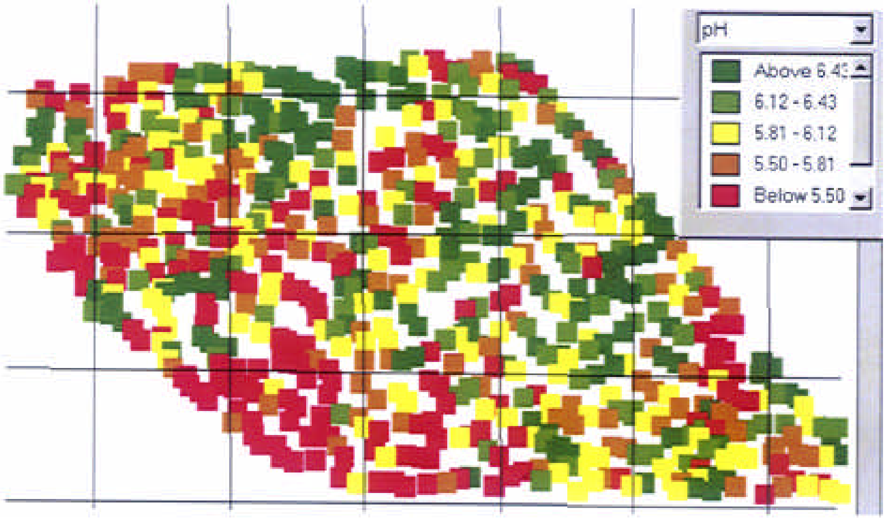
NO_3–N $29.90 (12.00–44.00); P $22.50 (10.00–35.00); K $19.40 (8.70–35.00). Approximate equivalent costs for similar analyses in USA, expressed in A$ are: pH $5.00; C $ 7.30; NO_3–N $9.50; P and K $6.70 each.

(b) Sample spacings shown depend on the mean value and hence will change with the mean.

The second and probably most concerning problem with the grid system is the fact that the level of intensity of sampling that most operators sample at, their accuracy can be influenced heavily by the location of their sample within the grid, or to put it another way the variation within the grid can be as great as that between grids.

The map below was made by Eric Lund from Veris in the US and it shows pH in a paddock as measured by mobile pH testing unit. The hatched squares represent a 1 ha grid pattern across the paddock. If you look within each 1ha grid you can see the full variation of paddock pH. If this was measured with the grid system, taking only one sample per grid, the results would be very heavily influenced by which area within the grid you chose to sample.

Despite these limitations with grid sampling, I have spoken to many devotees of the system. Dale Cowan who is based in Ontario, Canada runs a very successful business based on grid sampling and soil testing.



He has been saving corn growers in the area 10's of thousands of dollars in recent years by winding back their nitrogen inputs into corn production, however research done at the nearby Elora research centre by Greg Stewart has shown that producers in the area have been over applying nitrogen to corn for years and most of these savings could be achieved by simply winding back N, without the need for any grid testing.

The other big users of the grid system that I spoke to were the SOYL group in the UK. They are sampling phosphorous, potassium and pH on a grid system and then providing vary rate application maps. They have been claiming big savings in reduced inputs, but I feel in the case of P and K this will be a short term gain as they mine areas that have been over applied for many years. The issue of saving nutrients with the use of precision ag is an interesting one. In theory if farmers are supplying the correct amount of fertiliser under their current paddock average system, there is no way that vary rate application of nutrients can reduce inputs, they will be simply shifting nutrients from the current over fertilised areas onto areas that have been under fertilised.

ZONAL MANAGEMENT

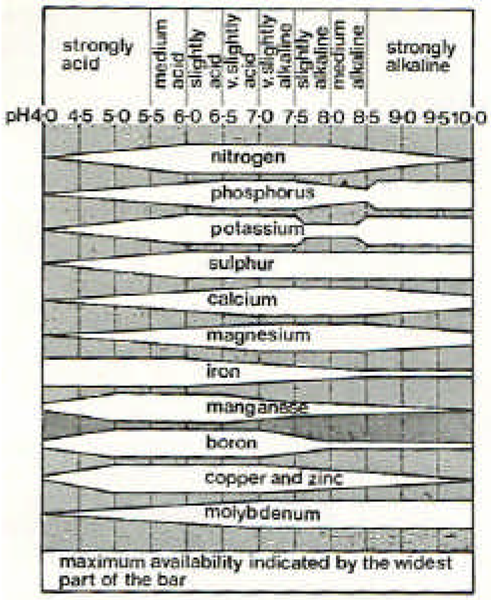
Early attempts at precision ag work were aimed at management of nutrients at a zone level. This involved dividing paddocks into various different zones based on soil type, yield maps or topographical maps and then layering combinations of all these levels of information together to form zones. These zones are then soil tested on an average basis and nutrients are then applied accordingly.

The main problem with this system is that there is often as much variation within zones as there is between zones and you end up with very similar problems to the grid sampling system, with results being heavily swayed by where you choose to sample within that zone.

The other major failing of this system is the difficulty in forming your zones. Using yield maps in dryland farming in Australia to form your zones poses a particular problem with flip flop syndrome. This syndrome is the complete reversal of yield in paddocks from year to year, with the high yielding areas of the paddock one year becoming the low yielding areas the next and vice versa.

The other major difficulty with forming zones is achieving an adequate correlation between the tool you are using to form the zone and the nutrient you are hoping to measure.

SITE SPECIFIC NUTRIENT MANAGEMENT



There are now a number of tools that allow us to measure nutrient levels down to a much more specific level. With the advent of GPS guidance, "on the go" testing and satellite imagery we can now measure nutrient variation down to less than one metre.

Soil pH

Correct soil pH is important for plant growth because of its influence on the availability of many soil nutrients (see table), some of these nutrients, for example aluminium, can reach toxic levels and restrict plant growth if pH is not managed.

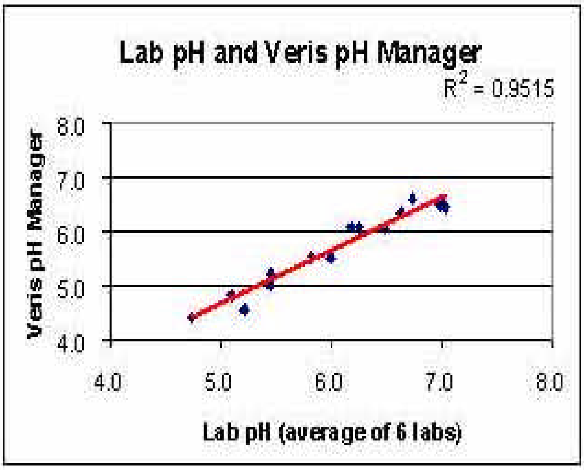
In Australia it is estimated that there is 33 million hectares of farming land with a pH of less than 4.8. Each year 100's of thousands of tonnes of lime are spread across paddocks in an attempt to correct this pH problem.

Currently the decision of when to lime and how much lime to spread is made after a standard soil test. There have been many trials to show that pH varies greatly across paddocks and this means that when lime is then spread over that paddock in a blanket application, areas of high pH will be receiving too much lime and areas of low pH will be receiving too little, resulting in poor crop growth due to nutrient tie up or other nutrients being available at toxic levels.

In an attempt to manage this spatial variation early research centred on grid sampling paddocks, but there are severe limitations to this method as I have previously explained.

Research has been under way concurrently in Australia (Mc Bratney et al - Sydney Uni) and the US (Lund et al - Veris Technology) into measuring pH using a mobile field testing unit.

These two units are driven across the paddock taking regular soil samples and measuring pH in the field as they go. A soil pH map is then generated and a lime application map generated from there. Both systems are very similar in their principle, but differ in the way that they gather soil and also in their testing mechanism.



The accuracy of the system has been tested comprehensively by both research teams against lab testing and the results from a Veris trial are shown here.

The big advantage this system has over grid sampling is that it can gather many more samples across a paddock at a much reduced price. Typical productivity of the Veris machine is shown in the table below.

Coverage Table				
	Transects			
	30'	40'	50'	60'
Speed (mph)	**Approx. samples per acre**			
4	23	17	14	12
6	16	12	9	8
8	12	9	7	6
10	9	7	6	5
	Transects			
	30'	40'	50'	60'
Speed (mph)	**Approx. acres per hour**			
4	13	17	22	26
6	20	26	33	39
8	26	35	44	52
10	33	44	55	65

Veris pH Manager

The veris unit has a shoe that is lowered into the soil repeatedly as the machine is driven across the paddock. As the shoe rises it comes into contact with two ion selective electrodes, these electrodes record the pH for that particular sample and are then washed with distilled water as the shoe returns to the ground for another sample. The shoe is cleaned of the previous sample by the next sample pushing through the shoe.

Australian Centre For Precision Ag pH Manager

The Australian version differs in that it has a fluted disc running continuously in the soil. The disc is running 20cm deep in the soil and is flicking soil up into a receptacle where it is then sieved to less than 2mm, before being mixed with CaCl and water and then measured for pH by two ion sensitive sensors.

This version of the mobile pH tester is still in the prototype stage at the moment, but it has a couple of potential advantages over the veris. Firstly it has a disc which is more rugged than the shoe design of the veris and it also has a penetration advantage over the shoe in extremely hard soils.

The second major difference is the way that either system makes allowance for the soils buffering capability, the Australian version is mimicking the standard lab test by firstly sieving the soil and mixing it with water and CaCl, before testing, whereas the Veris machine combines an EC survey of the soil measured through a series of large disc that are in constant contact with the soil.

They then use this EC survey to estimate soil type and thus buffering capability and although the two are reasonably well correlated I feel the Australian version has a distinct advantage in measuring this directly.

Soil Nitrogen

Since the early 1960's nitrogen has become the most widely used fertiliser in the world, so much so that we now consume around 80million tonnes per year (Fertiliser Indicators – I.F.A.). This coupled with the fact that nitrate pollution is a major threat to the environment and therefore agriculture, makes the accurate application of this nutrient of the utmost importance.

Historically farmers have used have use a variety of different methods to assess the amount of nitrogen needed to grow their crops.

This has varied from deep soil nitrate tests and NIR tissue testing to the humble tiller count, but all of them have shown limitations and the accuracy of many systems has been questioned.

The research done by Bill Raun et al (Oklahoma State University) showing that nitrogen levels can vary from the maximum reading in a paddock to the minimum reading in under 0.4m goes a long way to answering why we have struggled to get accurate answers with many of the different methods used over the years. The variation is just too great to measure with 20 soil cores across a paddock or 10 different tiller counts.

It is not only accuracy issues that plague the current testing methods used for nitrogen analyses, both the NIR (near infrared) tissue test and tiller counting require a lot of tedious paddock work collecting samples.

Because of the great variability in nitrogen across a paddock we need to make measurements of the entire paddock, not just samples across the paddock. This also has to be done at a price that is economically viable for farmers and can be done quickly.

Fortunately there is some technology that is now getting very close to providing that information and I will explain some of this technology below.

Hydro N Sensor

The N Sensor is a multispectral scanner that has the ability to gather chlorophyll and crop biomass as you drive across the paddock. Together these two pieces of information correlate very well with crop nitrogen content. The way the system works is there is a box located on the cab of the vehicle (usually a tractor) that emits light in two ranges and then records the reflectance given off by the crop. Light in the visible wavelength range (400-700nm) is a very good indicator of the leaf chlorophyll content and near- infrared (700 – 1000nm) an indicator of crop biomass.

A nitrogen application map is then created and farmers have the option of connecting directly to a vary rate spreader and spreading in real time, or producing a map during another operation and then spreading at a later date.

The system seems to work very well at predicting variation in nitrogen across the paddock and farmers in the UK have been seeing some real benefits in reduced lodging of crops and therefore big increases in harvesting capacity. However, after talking to Jim Wilson in Scotland I found that he and other farmers were struggling to make big yield gains from the system and there are a couple of issues that need to be addressed.

Firstly the fact that a great proportion of producers use the system in real time. While the system is obviously very good at finding nitrogen variations across the paddock, it takes no account of underlying problems that may be influencing the result. Sub soil constraints such as acid throttles and compaction zones, waterlogging or sodic sub soils can all restrict a plants ability to uptake nitrogen and if nitrogen is applied according to the N sensor there is the possibility these areas will receive the incorrect dose of N.

The second problem with the system is the fact that the sensors are operating over a 50m2 area and as nitrogen variation can occur over areas down to 0.4m, you are missing much of the nitrogen variation with your sensors.

Given that the main gains in using the system appear to be reduced lodging, I can see very little application of the N sensor in Australia.

The N Tech System

The N tech system developed by Bill Raun and others at the Oklahoma State University goes a long way toward overcoming the shortfalls of the N sensor in its scanning width.

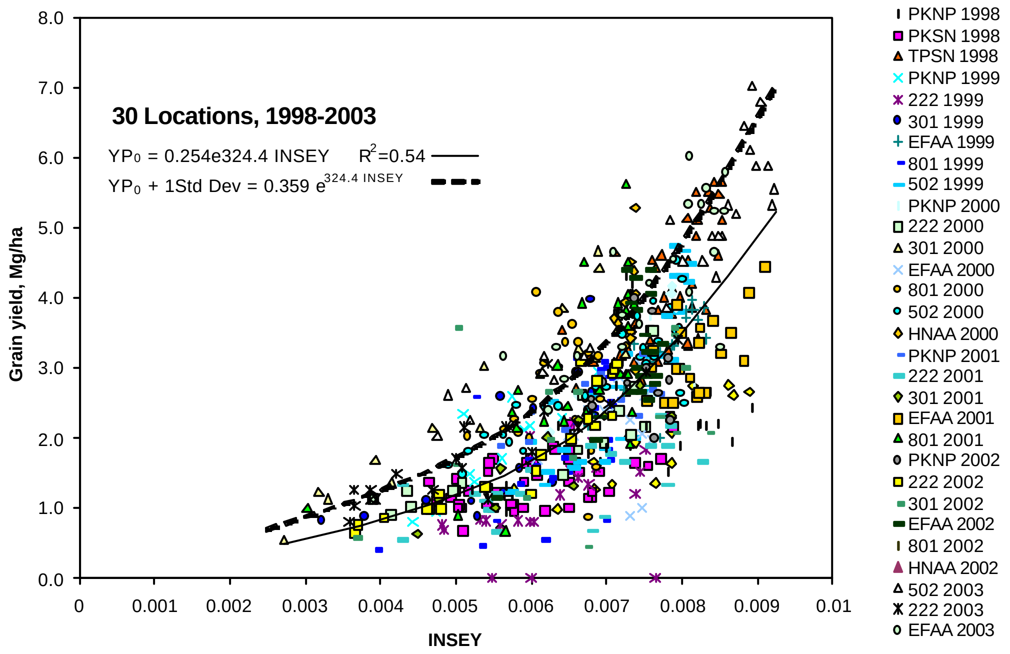
The way the system works is via a series of sensors mounted across the front of boomspray, 600mm apart.

The sensors are mounted in front of each spray nozzle and are constantly emitting two wavelengths of light, one in red (660nm) and one near infrared (780nm). The amount of light reflected from the crop is then measured and converted into a normalised difference vegetative index (NDVI) and from here converted to a nitrogen application map via a crop algorithm. Each sensor is actually connected to three nozzles delivering different rates of liquid nitrogen at 1X, 2X and 4X and through an electric solenoid is able to quickly vary rates on – the – go.

To determine the amount on nitrogen to apply to a crop a yield goal must be put into the equation and this is done via an in season estimated yield (INSEY). The INSEY reading is simply an indication of how the crop has been growing and is arrived at by the following formula.

NDVI reading / No growing degree between sowing and sensing days > 0.

There is an extremely good correlation between INSEY and final yield (Bill Raun et al 2001) and the graph below shows the results of trials done in 30 different locations.



The second challenge faced in nitrogen recommendations is the responsiveness that different paddocks or even different areas of paddocks show to nitrogen applications. This can be influenced by a number of factors, but the variation in nitrogen mineralisation has a large affect on whether or not soils will show a response.

Raun & Johnson, 2003 analysed a long term trial in Oklahoma and found that check plots (zero nitrogen applied) actually yielded more than or equal to the nitrogen strips in some of the years, indicating a zero response to N.

They overcame this challenge by applying a nitrogen rich strip (non limiting nitrogen) across each paddock. They then run the sensors over the nitrogen rich strip and the check strip on the same day to arrive at response index via the following formula:

Response index = NDVI non limiting strip/ NDVI check plot

The yield potential if nitrogen was applied is derived by multiplying the yield potential (derived from the INSEY) by the response index (from the nitrogen rich strip) and simply creating a nitrogen application map form the nutrients removed from this potential yield.

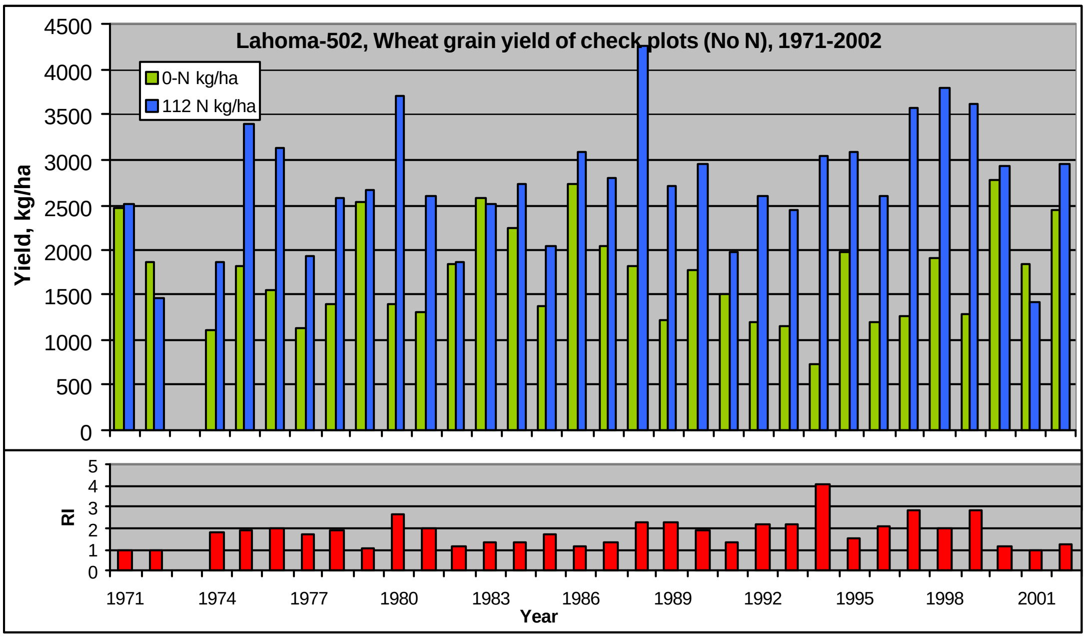


Figure 3. Grain yields from 1971 to 2002 in plots receiving annually applied N at 112 kg N/ha and plots that have never received fertiliser N, and the response index (yield from the 112 kg N/ha plot divided by the check or 0-N kg N/ha).

The science involved in creating the algorithms for each crop is very sound and has been trialled in many different areas, under many different climatic conditions; however I still have some personal reservations about the way it would work under a “bob tail” spring (spring shortened due to lack of rain) here in Australia.

The basis of the algorithm is that if you have been experiencing dry conditions, then the crop development will have been slow and this will be reflected in a low NDVI number and hence nitrogen will be cut back, but I wonder if you have been experiencing good growing conditions up until tillering and you apply your nitrogen accordingly, what happens if we experience a typical tough spring here and rainfall simply dries up – this must surely be a scenario for haying off.

This aside I think the system has a lot of merit and probably the biggest draw back is the cost.

The technology retails for around US$1000/foot and this is after you have paid for the boomspray.

A much cheaper option currently available with N tech is their handheld sensor, which can be used to assess nitrogen strips and give you a paddock average nitrogen rate. It of course doesn’t give you access to the vary rate technology associated with the boomspray, but at around US$3000 it is a way of trying the technology before making a large financial commitment.

Satellite Imagery

Satellite imagery is probably the ultimate in looking at your entire paddock in one easy operation and relatively cheaply.

I spent most of my time in France looking at two similar versions of satellite imagery and they impressed me a lot.

The EADS group, who manufacture satellites and the airbus aircraft among other things, have set up an agricultural extension of their satellite work.

They offer different packages to the farmer ranging from a simple tiller count up to a full package including fungicide application maps, growth regulator maps, multiple nitrogen application maps and final yield estimates. This is all done from satellite images which are measuring chlorophyll and leaf area index (LAI).

The system has been operating in France since 2002 and has grown from 4000ha that year to a projected 200,000ha for next year.

At the moment in Australia, Terrabyte Services based in Wagga are trialling the system.

I have just had a number of paddocks imaged with them at $3/ha, but at this stage they are not offering nitrogen application maps until further research has been done here locally.

After talking to John Lucas (Terrabyte), he tells me they hope to have the system up and running for next years cropping season and he was unsure of the cost at this stage, but it was likely to remain the same for a simple image, but would be higher for nitrogen maps.

Currently after the image is taken the data is sent to France where it is processed into nitrogen application maps.

Arvalis (an agricultural consultancy firm) have been working with EADS on this project since it started and they put in a lot of other data from each farm (for example yield goals, variety, soil types etc) before combining this with the satellite image to arrive at a nitrogen application map.

This system definitely has a place in managing nitrogen; it provides detail down to the sub metre accuracy demanded of nitrogen management and also provides the individual farmer with a chance to have some input into the maps before nitrogen is applied.

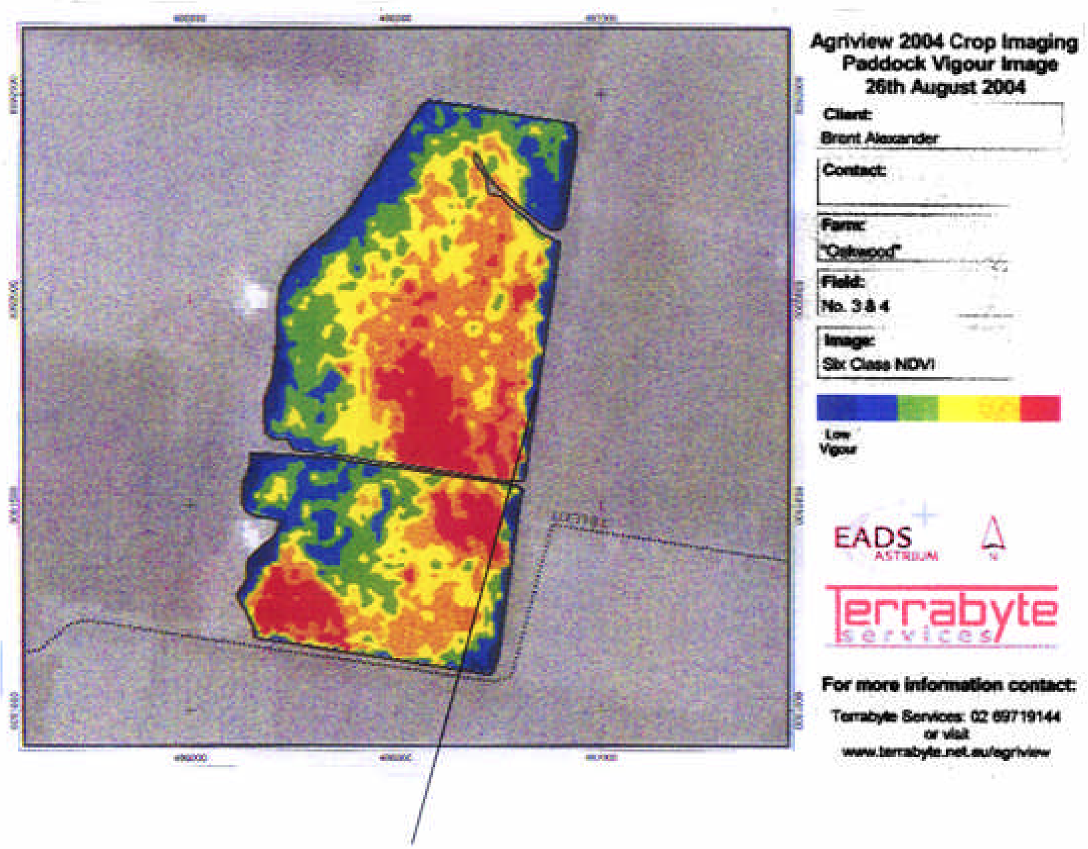
They have had some difficulty in parts of Europe and the UK with cloud cover interrupting the satellite image, but I think this will be rare here in Australia.

The second company I visited was Geosys and they ran a very similar version of the satellite imagery work of EADS, except for the fact that the farmer was in control of the entire operation.

The way it worked was the farmer paid an annual subscription to have access to the satellite images at any time of the year. With the package you also get a software programme that is very similar to the Arvalis set up and this enables the individual farmer to enter his own inputs at home for each individual paddock.

This form of the system obviously requires more input from the individual, but it is important to have ultimate control over the satellite information. I guess the clearest indication of this can be seen with my own image from a wheat crop this year (shown below). The area on the eastern fence shows a very low vigour, if this map had vary rate nitrogen applied without my input, there would be more nitrogen applied here, but because I know there is a tree affect here, I now have the ability to override the system and cut back or even not apply nitrogen in these areas.

Another important difference between the two systems is that the Geosys system removes one more level of input and thus another middle man adding to the cost of the operation.



Tree effect on eastern fence.

Phosphorous

Phosphorous is an essential element for plant growth and plays an important part in the role of photosynthesis. It is used extensively around the world and is second only to nitrogen in yearly consumption (around 33 million tonnes world wide per year).

Phosphorous, however, differs markedly from nitrogen in the way it behaves in the soil. It is very stable and not prone to the leaching that is associated with nitrogen and is also not prone to the temporal variation associated with nitrogen.

These factors are important when you are considering how to measure soil phosphorous levels, as it means your standard paddock average test or gird sampling have much more credence when measuring phosphorous.

Historically phosphorous has been measured using the paddock average system, but recent advances in precision ag and grid sampling have lead to researchers and farmers looking to a better means of establishing phosphorous levels.

It is a well established fact that crop yields are greater when soil P levels are at an optimum level. This level will vary with crop type and soil type, but one thing remains constant that no matter how much P is applied with the crop the yield will still be greater where the soil reserves were higher initially (see graph).

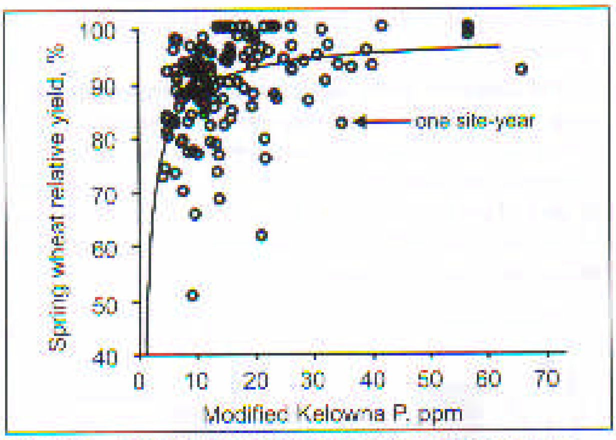


Figure 2. Phosphorus soil test calibration data for spring wheat in Alberta (McKenzie et al., 1995).

With the advent of yield mapping some areas of paddocks have been shown to be consistently out yielding the paddock average, whilst other areas are yielding well below.

If blanket applications of phosphorous have been used in the past, it stands to reason that large areas of some paddocks will becoming deficient in phosphorous. This could have a severe impact on the paddock average as crop yields begin to decline in the traditional high yielding areas.

This has been backed up by grid sampling performed in the US and UK; where large variations in soil p have been shown across paddocks. The problem in Australia, in broad acre situations, is that the cost of extensive grid sampling is prohibitive, but after talking to Chris Dawson (IFA – England) and Jim Wilson (Farmer – Scotland) there is a solution.

They are both independently trialling a very similar system of phosphorous management.

Basically yield map data is collected for a number of years and consistently high yielding and low yielding areas are established. These areas are then grid sampled within their "yield zone" and phosphorous levels are established.

They then plan to correct any deficiencies and mine areas of high phosphorous until the paddock is evened out.

Both then plan to use their yield maps each year to establish nutrient removal and simply replace these nutrients with the following crop.

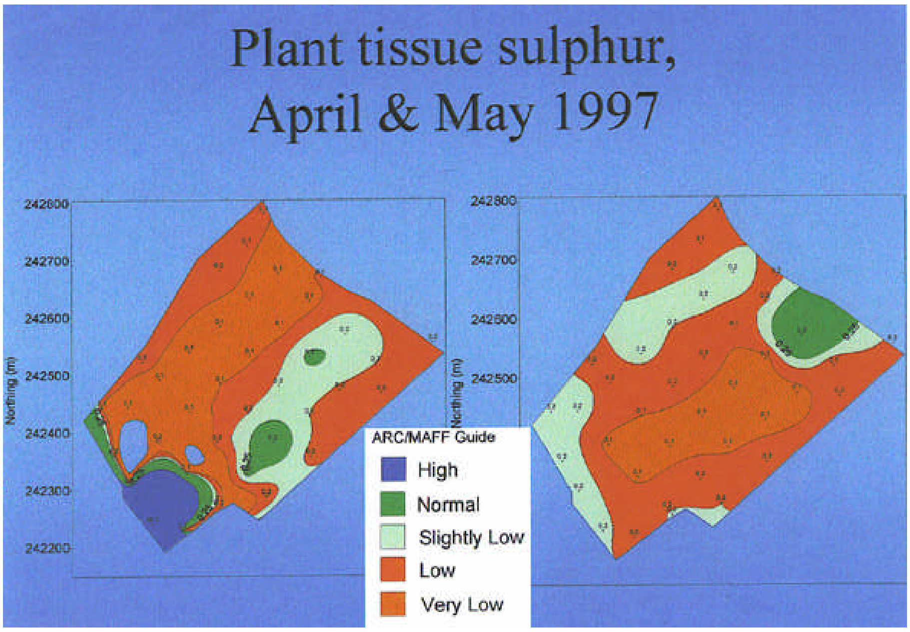
This system reduces the cost of grid sampling substantially by using yield map data as guide as to where to sample.

The SOYL company in the UK are also claiming large fertiliser savings through grid sampling, but if a farmer has been applying the correct amount of P in the past then the total P used will not change, it will just mean more is applied in some areas, while the high P levels are mined.

Potassium follows a very similar pattern to phosphorous in its behaviour, but because of its limited use in broadacre agriculture in Australia I have not researched it to any great extent.

Sulphur

Sulphur like nitrogen is very difficult to track in the soil because it is very mobile and like nitrogen the temporal variation is huge. If you look at the two paddock maps below you can see the change in soil sulphur readings over one month. The testing was done through The Arable Group in the UK and you can clearly see that if you applied sulphur to this paddock after testing it in April you would be using a completely different map to the one you would have used if you tested the paddock in May.



This temporal change makes testing for soil sulphur levels very difficult.

Added to the temporal variation is the fact that unlike nitrogen which has a very good correlation with chlorophyll content and plant biomass, sulphur does not have this correlation with any of the current sensing or satellite imagery work being done.

This means we are limited to a paddock averaging system of soil testing or tissue testing and that any sort of precision work with sulphur is a long way off at this stage.

I did come across an interesting new version of the sulphur tissue test at Rothamstead in the UK. The name of the test is the Malate test and the difference between this test and current testing methods is that rather than measuring total S in the plant you measure the ratio of malate to sulphur.

Malate is an organic acid which is present in all plants and if the plant becomes deficient in sulphur the malate level rises. If the plant then picks up sulphur the malate level will fall. The beauty of the test is that the malate levels rise and fall very slowly in comparison to the sulphur levels in the plant. This inturn means you avoid one of the major problems associated with tissue testing and that is your test is only a snapshot in time.

If you have a look at the table below you can see how much improvement there is over current sulphur tissue tests and grain tests. The research work was done in the UK by Rothamstead.

Table 1. Percentage of winter wheat samples misdiagnosed as sulphur sufficient based on three tests

Year	Malate:sulphate ratio	N:S ratio (grain)	N:S ratio (leaves)
2000	2%	20%	37%
2001	7%	11%	10%
2002	3%	8%	6%
Average	4%	13%	16%

Trace Elements

Trace elements although used in much smaller quantities than the macronutrients are still just as important to crop growth.

The limiting factor theory has been known for some time and the fact that no matter how much of one nutrient you apply you will not lift yields if something else is limiting is best represented by the familiar barrel analogy shown below.

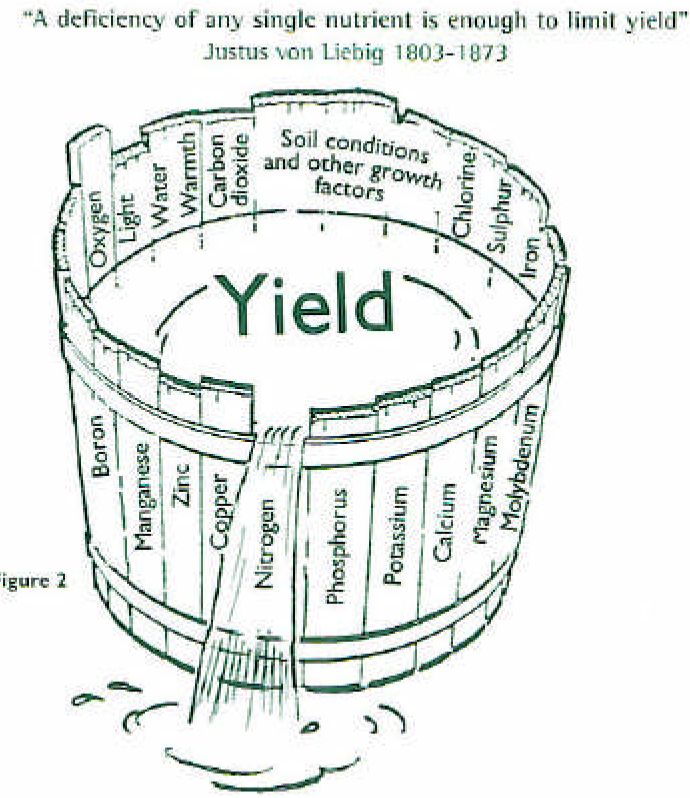


Figure 2

With the large increase in crop yields that has taken place over the last 20 or 30 years; soils that once contained adequate levels of trace elements are now showing signs of deficiencies.

This fact is clearly shown in dramatic responses to application of deficient trace elements, but it is also showing up in human health issues as well. It is currently estimated that 64% of the world's population is deficient in iron (Graham et al 2001).

The standard approach to testing for trace elements has been the use of extensive soil testing followed by several years of in field testing, before a blanket recommendation has been applied. This was carried out across many countries during the 1960's and 70's, but due dramatic changes in the types of crops grown since then and the many changes in cultural practices and herbicide use combined with large increases in yields, the information is now mostly irrelevant. The cost of redoing this across many acres is prohibitive and there has been some interesting work done in Australia on “weight of evidence” modelling (Wong 2003).

The theory of it revolves around the fact that many trace elements are highly correlated to soil type.

Research work by Richard Bell and others at the Murdoch University has included the mapping of areas in south Western Australia that are likely to suffer from boron deficiency, simply by correlating boron levels to soil type. They found that soils with a pH in the topsoil of less than 5.5 were highly likely to be low in boron and that soils that had a pH of greater than 7 in the subsoil would more than likely contain adequate levels. They also found that soils with a clay content greater than 15% were unlikely to suffer from boron deficiency.

This is certainly a much quicker and cheaper option of identifying potential problems than using exhaustive soil surveys, as most of this soil type information is already available.

This information is very valuable as an indicator to farmers to be aware that these sorts of problems may occur if they farm on a particular soil type, but the information needs to be brought down to a much more specific level if we are going to manage these nutrients to the sorts of levels required for modern day cropping.

Most of the farmers I talked to in the UK and North America were using tissue testing to establish if trace elements were deficient and this was mostly in response to an observed deficiency symptom during crop growth. They were then correcting the problem with a liquid fertiliser in crop or returning the following year with a granular or liquid.

Many like me had found that the standard soil test was unreliable in establishing trace element problems.

The Balance

Balancing Within Soil

There has been a lot published lately on the importance of having the correct balance of nutrients in the soil. Most of the information is based on a book published in the 1930’s by Neil Kinsey (Hand’s On Agronomy) and it is based on work done by Albrecht at the University of Missouri during the early part of the 20th century.

As I travelled around overseas and particularly in the UK I found that most of this information was not substantiated by trials and this is also backed up by an article in Potash News by Johnny Johnston and John Hollies. In fact in this paper they have actually done some trial work to disprove many of the recommendations and claims made by proponents of the Basic Cation Saturation Ratio (BCSR) system.

The basic concept of the system is that there is an ideal ratio for the base cations Ca, Mg, K, and Na in the soil, but if you look at the two tables below you will see varying cation ratios but very similar yields.

Table 2 is a trial done on grass yields at Rothamstead and the Ca: K ratio varies greatly between the two soils, but the ratios in the plant are identical and the yields very similar.

Table 2: Levels of calcium (Ca), magnesium (Mg) and potassium (K) in soil and in the grass[1] grown on these soils. Average of four years' data.

Annual yield t/ha	Soil					Crop % in dry matter			
	Analysis %	Ca	Mg	K	Ca: K ratio[2]	Ca	Mg	K	Ca: K ratio[2]
Rothamsted 10.0	mg/kg %	3290 94	42 2	244 4	26:1	0.6	0.11	3.5	0.2:1
Woburn 10.8	mg/kg %	1300 79	156 16	158 5	16.1	0.5	0.19	3.3	0.2:1

[1] Ryegrass ley given 300 kg N/ha annually divided equally for 6 harvests of grass.
[2] Ratio based on equivalents and the sum of the three cations.

The story is very similar for the wheat trial below. According to the BCSR system the cation ratio for soil no 1 is ideal, but in the second soil the Ca + Mg % is too high, yet the yields are almost identical.

It seems that as long as there is enough of each nutrient within the soil the plant has the ability to source what it needs and turn it into yield.

Table 3: The yields of winter wheat grown on two soils of contrasting base cation ratios but with sufficient potassium and magnesium in both.

Soil No.	Soil pH	Cations as a % of total				Yield grain t/ha	Cations as mg/kg (Index)			
		Ca	Mg	K	Na		Ca	Mg	K	N
1	7.2	76	4	4	0.2	9.6	2380	66(2)	247(3)	10
2	7.0	69	19	8	1	9.8	1460	243(4)	347(3)	32

Of far greater importance in Australia, and probably most of the world, is the ability to balance nutrients with the weather.

Nitrogen in particular creates its own set of problems if it is not matched well with rainfall.

Typically with wheat, crops that are over fed are prone to haying off and subsequent yield reductions and also small or pinched grain.

The use of weather modelling has enhanced farmers' ability to match nitrogen to rainfall, but there is still a large element of risk associated with them as they will only give a percentage chance of a rainfall event and not a guarantee.

Balancing With The Environment

Around the world there is increasing pressure on farmers to reduce the pollution of waterways with nutrients. In some countries there is already legislation in place limiting the amount of nutrients farmers can apply; limiting when they can apply nutrients and in some cases farmers are heavily taxed on pesticides and fertilisers in an attempt to limit their use.

If we do not make a voluntary push towards getting the balance right between production and fertiliser use, those of us in the remaining countries, such as Australia, will soon face some sort of enforced legislation.

All Canadian farmers in the province of Ontario must already perform a government approved nutrient budget at the start of each year.

There is also a voluntary programme in operation in which farmers work through a workbook to assess the impact their current farming practices are having on the environment. This covers areas as diverse as fertiliser use, to the location of diesel bowsers and the chance of oil spills. The programme has an uptake of 50%, which is very high considering this is still voluntary at this stage.

I spent some time talking to George Thompson (Canadian scholar in Ontario) about his precision ag work and in particular the site specific management of nitrogen. He told me he was making very little money from the exercise, but was persisting with it because he felt that some time in the future government authorities would demand this level of information and precision in nutrient application.

New Zealand farmers are also having considerable success in a voluntary programme they have initiated to fence off all waterways from livestock in an attempt to reduce faecal contamination. They too have legislation in place around some of their sensitive areas such as the Lake Taupo region in the north island, where producers are limited in their fertiliser applications in an attempt to reduce contamination of the lake and all New Zealand farmers will be required to perform nutrient budgets by 2007.

Similarly the United Kingdom has introduced Nitrate Vulnerable Zones (NVZ's). Under this legislation farmers are not only limited to the amount of nitrogen they can apply (170kg N/ year), but also the time of year they can apply nitrogen. If they want to spread outside the time guidelines the authorities must have a written application in at least three days prior to the planned work. All farmers must maintain records of applications for at least five years and provide access to any authority to test ground water, view records etc.

The Europeans have probably gone the furthest down the nutrient control path. French farmers have only recently avoided a tax on nitrogen in favour of compulsory budgets, but the Danes have been taxed on fertiliser and chemicals for a number of years.

They have reduced their nitrogen use by 50% since the 1980's, but it has come at a cost. Wheat protein levels there have dropped from 12% to 9% during the corresponding period.

In talking to researchers at Rothamstead in England I came across another interesting trend in soil sulphur levels.

If you look at the graph below you will notice that there has been a steady decline in soil sulphur levels since the 1970's. This decline has been so marked that many producers in the UK are, for the first time, now being forced to apply sulphur to crops.

The decline has been attributed to the reduction in emissions from heavy industry and the resultant reduction in sulphur enriched acid rain.

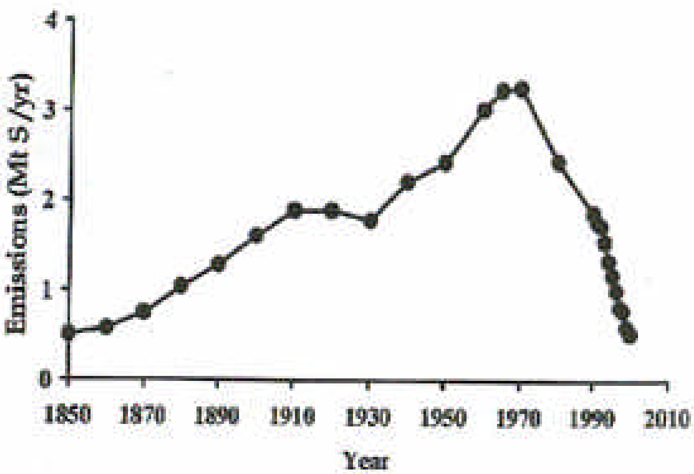
Obviously the push for cleaner air has lead to farmers in the UK bearing the cost of a better environment and while I am not condoning industry polluting the atmosphere, it does give you some idea of what can happen if the pendulum swings and farmers begin to suffer for a better environment that everyone is enjoying.

It is exactly the same in Denmark, where the protein levels in wheat have dropped so much since fertiliser has been taxed and while it has probably had a limited influence on farmers profitability because most of this grain goes into the feed market, it would be quite devastating if the same thing happened here in Australia with our focus on export quality markets.

If there is to be a balanced approach to nutrient use within our environment and that if there is major cost involved in compliance, then the question has to be raised – who pays?

SULPHUR INPUTS TO LAND.

Emissions.



Change in sulphur dioxide emissions in the UK with time (expressed as sulphur).

UKRAINE

My tour of the Ukraine was set up by Geoff Sansome (UK Nuffield scholar) who works for DEFRA, the UK department of ag equivalent.

The UK is putting a lot of money into Ukrainian agriculture. The two organizations I was working with had a budget of A$15million for the next 4 years to spend in the Ukraine on rural development.

There is a lot of work to do in rural areas; as the old state run farms were not only responsible for employment, but also ran schools, bus runs, basically all rural infrastructures.

The two UK organizations were working with: educating farmers, income stabilization, legal help, financial backing, community development and also training for new jobs.

The Ukraine is a place of two stark contrasts. The people of the cities are, in general living a very civilized life, in cities that would not be out of place in most of Western Europe. Kiev has many beautiful buildings and huge areas of parkland, although it is a little unkempt.

As soon as you leave the city and head down the highways you see a completely different picture and although the highways themselves are in good condition, they are littered with people in old broken down vehicles, people on pushbikes and many on foot.

There are also some horse drawn vehicles mixed in amongst them. The closer you get to the rural villages, the more the standard of living drops.

Farmers are amongst the poorest people in the Ukraine and as one advisor with the Kiev Rural Advisory service put it to me; there are three ways to go broke in the Ukraine: cards, women and agriculture.

Prior to the commencement of the Communist regime, farmers enjoyed relative prosperity. They farmed in some of the best soil in the world and had built up some very good farms; this of course meant they were very opposed to Communism, as their hard earned assets were stripped from them.

Farming however fared reasonably well under communism, as food was seen as a very important part of life and Russia was keen to see it prosper. Most of the decay in the farming regions has taken place since 1991 and the fall of communism.

There are two very limiting factors that are impacting on farming at the moment, firstly the fact that farmers were only granted 50ha under the equalization scheme and there is now a moratorium on any further land sales, which has severely limited the scale of farms.

Secondly is the fact that interest rates are running at 25% and compounding this problem is the fact that farmers only have 50ha of land to borrow against, which is not enough for the banks to use as capital; even if the farmers did want to risk borrowing at 25%.

There seems to be a large hangover from the old communist days, in that the 50ha handed out and the land sale moratorium is designed to give everyone an equal opportunity at owning land and prevent western investment in Ukrainian agriculture.

Farmers do have the opportunity to expand their enterprises through rental agreements and there are some quite large “enterprise farms” that have done this.

Some of these farms actually purchased more land prior to 2002 when the land sale moratorium was introduced. There was a bizarre rule that was in place up until then, that enterprise farms could purchase more land, but individuals could not. I enquired as to why farmers couldn’t just become an enterprise and was told that they could, that none of them could afford the legal fees associated with becoming a company or pay an accountant to audit their books (which is mandatory for all companies).

I had always thought that the main reason these old USSR countries were struggling with their farming was because of a lack of infrastructure, but it seems that this a minor concern for them. They appear to have access to chemicals, fertiliser etc and machinery although very poor here, can be imported relatively easily.

Their grain varieties seem to yield reasonably well. I visited the Crop Production Institute in Kiev and the Agricultural University in Bila Tserkva and both of these institutions were achieving yields in wheat of up to 12t/ha.

They do seem to have some quality issues, but this may have been mainly to do with their unseasonably wet harvest they were currently experiencing and there is a large lodging issue with many varieties.

From what I have seen, their poorest piece of infrastructure seems to be grain storage facilities. I toured the facilities in Bila Tserkva and they were in very poor condition and this storage was run by a university in which the director had recently been awarded a certificate of merit for the way he ran the University farm.

Having said that varieties were yielding well under research conditions, the story out in the country was very different. Average yields for Ukraine are around 3.5t/ha and this is on arguably the best black soil in the world in a 400 – 700mm rainfall belt.

This relatively low figure is mainly due to finance, as farmers don’t even have the money or the ability to borrow for inputs.

The richer or enterprise farmers are achieving yields of 8t/ha and with the price of wheat here being very similar to Australia, they are making quite good money.

Average costs for inputs on wheat are around US$500/ha and land can be rented for US$20/ha, so there is money to be made here.

I also had the opportunity to tour around the city of Kiev with two tour guides who used to work for the Soviet run Intourism. It was fascinating talking to these women who told me that they were watched very closely by KGB because they were the only people who had access to the western world. Their entire tourist agenda was set by the KGB and every tour that took place was accompanied by a KGB officer.

Conclusion

In the past all fertiliser decisions were made based on a replacement theory. It basically meant that farmers averaged their yields, multiplied them by the nutrients contained in each tonne and came up with a figure for the next year's fertiliser application.

The system was backed up with the standard soil test, which was primarily used as a monitoring tool, to see if nutrients were building up in the soil or in decline.

Both the testing of the soil and the application of the fertiliser were done on a paddock average basis and made no account for the huge variation that exists across all paddocks.

The advent of GPS and the ability to measure nutrients site specifically has given farmers a whole new way of looking at their nutrient requirements.

We now have the ability to measure a number of nutrients down to sub metre level and also have the technology to apply these nutrients at this level.

The standard soil test will remain as a monitoring tool, but its more intense cousin, the grid test, will have limited application in broadacre agriculture in Australia.

I can see the grid test being used to intensively sample parts of paddocks or certain zones for the use of phosphorous and potassium, but apart form this, its cost and level of detail will make it unviable.

The first foray into precision ag was the use of zones, which are commonly formed with the aid of EM surveys, yield maps and topography maps by themselves or in combination with other levels of paddock information.

These zones are then used as a guide to further soil testing. I saw some interesting work with using them to test the highs and lows of phosphorous across paddocks in the UK, but apart from this I think we will in the future be demanding more information than these zones can give us.

They suffer from a similar problem to the grid test, in that they do not measure down to a small enough level and commonly, because of this, there is as much variation within zones as there is between.

Two of the nutrients we use in large quantities can now be measured down to sub metre levels.

The mobile pH tester has the ability to measure pH across paddocks at an infinitely variable distance and there are a number of different methods of measuring nitrogen down to this level.

With an improving ability to predict at least probabilities of rainfall, we can now start to prescribe fertiliser recommendations for crops rather than use the old replacement methods.

This ability will be required by farmers in the future as they strive to remain competitive, but equally important this level of preciseness will also be required by the general public, government regulators and our consumers as we all work towards a better environment.

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